CHAPTER 2

SELF-COMPACTING CONCRETE

2.1 GENERAL

In the last two decades, concrete has no longer remained as a material just consisting of cement, aggregates and water but it has become a building material with several new constituents to meet many varied requirements of the construction industry. The binding material used in modern concrete mixes is not portland cement only but a combination of cement and supplementary cementitious materials (SCM) including fly ash, slag and silica fume. In addition, chemical admixtures are used to improve concrete properties at fresh and hardened stage, in a cost effective manner.

2.2 SELF-COMPACTING CONCRETE

Nevertheless, self-compacting concrete (SCC) is a high performance concrete having very low viscosity and high resistance to segregation, does not need any kind of vibration during casting. SCC is an innovative development in the construction industry due to numerous advantages of it over normal concrete. SCC is the most popular example of customized concrete in plastic state by Okamura et al. (1999). SCC can flow readily into thin section, places around closely spaced reinforcements, filling formwork without any consolidation and segregation. SCC can be placed into every corner of a form work, becomes consolidated and hard purely by means of its own self weight, hence eliminating the need of vibration or other types of consolidating effort. Hence SCC has been easily accepted in the construction industry.
Any highly flowable concrete may not be self-consolidating because concrete must flow under its own weight, also fill the formwork and achieve uniform compaction without segregation. Fibres are sometimes used in SCC to enhance its strength properties and delay the onset of cracks due to continuous heat of hydration resulting from high cement content.

2.3 DEVELOPMENT OF SCC

In general, the concept of SCC is not new. The history of self-compacting concrete (SCC) dates back to late 1980s. For special applications such as underwater concreting, vibration of placed concrete is simply impossible. In such circumstances, concrete needs to be placed without any compaction by Bartos et al. (2000). Early self-compacting concrete relied on very high content of cement paste and once superplasticizer was available, it was added in the concrete mixes. The mixes required specialized and perfectly controlled placing methods in order to avoid segregations. The high content of cement paste made concrete prone to shrinkage. The overall cost was very high and application remained limited.

The introduction of SCC was associated with the drive towards the better quality concrete pursued in Japan around 1983, where the lack of uniform and good compaction had been identified as the primary factor responsible for poor performance of concrete structures (Dehn et al. 2000). Since there was no practical means by which full compaction of concrete in a construction site could be guaranteed, the focus turned on to the elimination of the need to compact by vibration. This reason led to the development of the first practicable form of SCC. The idea of formulating SCC was first proposed by Prof. Okamura in 1986. Nevertheless, SCC was first developed in Japan in 1988 by Prof. Ozawa at the University of Tokyo to ensure homogeneity and compaction of cast-in-situ concrete within thin structural
elements thereby to improve the durability of concrete structures. Many Japanese contractors quickly followed the idea. An important factor was that each of the large contractors formulated their own testing methods and devices (Bartos, 2000). By 1988, the concept of SCC was developed and ready for the first real scale test. The first prototype of SCC was made using materials available in the market. The prototype performed satisfactorily with regard to drying; hardening shrinkage, heat of hydration and denseness after hardening. The prototype was named as 'High Performance Concrete'. At the same time, HPC was known as a concrete with high durability due to low water-cement ratio by Professor Aitcin (Okamura et al. 1999). Since then, the term HPC has been used around the world to refer to high durability concrete, Prof. Okamura has changed the name for the newly invented concrete to 'self-compacting high performance concrete' in 1997.

After 1988, European countries started working on SCC. During 1990~2000, very active research was going on in Europe and they published many specifications and guidelines for SCC. Moreover in November 2002, the first North American Conference on design and use of SCC was organized. There have been a large number of researches carried out throughout the world to optimize the fluidity of SCC, enhance its strength and durability in a cost-effective manner. According to Hajime Okamura & Ouchy (1999), the solution for achieving durable concrete structures independent of the quality of construction work, is the use of self-compacting concrete.

The reason for the development of self-compacting concrete was the problems associated with the durability of concrete structures that arose in Japan during 1983. To make durable concrete structures, concrete must be sufficiently compacted by skilled workers during casting. Due to gradual reduction of skilled workers in Japan, the quality of construction work also
reduced. The cause for the poor strength & durability performance was inadequate consolidation of concrete. Due to this fact, the only solution available for the achievement of concrete structures with more durability was to use self-compacting concrete in construction. This is explained in Figure 2.1.

![Diagram of Skill of workers and Self-compacting concrete leading to Durable concrete structures](source: Ouchi and Hibino, 1997)

**Figure 2.1 Necessity of self-compacting concrete**

SCC consists of the same constituents as conventional concrete. It contains cement, aggregates, water with the addition of mineral as well as chemical admixtures in different proportions. In some cases, the mineral admixtures like silica fume or fly ash which is used as extra fine materials. Chemical admixtures like high range water reducing admixtures (HRWRA), viscosity modifying admixtures (VMA) are used to change the rheological properties of concrete. SCC has a higher content of fine particles, leading to improved flow properties than conventional concrete as shown in Figure 2.2.
There are three essential properties at fresh level for SCC, i.e. filling ability, passing ability and resistance to segregation. However, its mixture components are similar to other plasticized concrete. The use of chemical admixtures enhances the filling and passing ability of SCC. This enhanced fluidity of SCC effectively for highly congested reinforced columns and beams. The fresh properties of SCC may be affected by the physical characteristics of materials and mix proportioning. The mixture proportioning must be based upon creating a high-degree of flowability while maintaining a low water binder ratio. This is achieved by using HRWRA combined with VMA to ensure homogeneity of the mixture.

(Source: Dehn et al. 2000)

**Figure 2.3 Basic concept of self-compacting concrete**
The use of SCC facilitates casting of concrete by eliminating the need for vibration. Given the highly flowable nature of SCC, care is needed to ensure excellent filling ability and adequate stability. This is particularly important in thin structural members and wall elements, where concrete may block the flow, segregate and exhibit bleeding and settlement resulting in defects reducing the mechanical properties, durability and quality of surface finish.

2.4 HOW TO ACHIEVE SELF-COMPACTABILITY

The process of achieving self-compactability involves not only high deformability of paste or cement mortar but also resistance to segregation in between coarse aggregate and mortar, when concrete flows through congested reinforcements. Okamura & Ozawa (1994) employed the following methods to achieve self-compactability.

a) Limited aggregate content

b) Low water-powder ratio

c) Use of superplasticizer

The frequency of oscillation and contact between aggregate particles increases if the relative distance between the particles decreases. The internal stress will increase when concrete is deformed particularly near obstacles. The energy required for flowing is consumed by the increased internal stresses, leading to blockage of aggregate particles. This blockage may be avoided by

i) Limiting the coarse aggregate content to a level lower than the normal. The energy consumption of the coarse aggregate is
intense, hence limiting the coarse aggregate content will avoid this blockage.

ii) High viscous paste is required to avoid the blockage of coarse aggregates when concrete is flowing through obstacles. When concrete is deformed, paste with a high viscosity reduces localised increase in internal stresses, due to the approach of coarse aggregate particles.

iii) High deformability may be achieved by the employment of superplasticizer, keeping the water-powder ratio to a very low level.

The basic concept of SCC is explained in Figure 2.3. The ratio of coarse aggregate volume to its solid volume in SCC must be lesser than conventional concrete. The degree of packing of coarse aggregate in SCC is around 50% to reduce the interaction between coarse aggregate particles when concrete deforms. Also the ratio of fine aggregate volume to its solid volume in SCC must be lesser than conventional concrete. The degree of packing of fine aggregate in SCC is approximately 60% so that the shear deformability may be limited when concrete deforms. The viscosity of the paste in SCC is the highest among the various types of concrete due to its lower-water powder ratio.

2.5 CONSTRUCTION ISSUES

After the formulation of self-compacting concrete in 1988, the use of self-compacting concrete in construction activities is gradually increasing. The main reasons for the employment of self-compacting concrete can be summarized as follows.
- To reduce the construction period.
- To guarantee full compaction in structures - especially in confined zones where vibrating concrete is difficult.
- To reduce noise level due to vibration

By employing SCC, the cost of vibrating concrete can be saved and the full compaction of concrete in the structure can be assured. Also the cost of chemical and mineral admixtures is compensated by the elimination of vibration and work done to level the surface of the normal concrete (Khayat et al. 1997). However, the total cost of construction can not always be reduced, except in the case of large scale constructions. The reason being the conventional construction system is strongly based on the vibrating concrete for compaction. Over vibration of concrete may cause segregation of concrete, has been a hurdle to the rationalization of construction work. Self-compacting concrete can greatly improve construction systems that were previously based on conventional concrete requiring vibrating compaction as per Figure 2.4.

(Source: Ouchi et al. (1997))

Figure 2.4 Rational construction system proposed by Prof. Ozawa
This sort of compaction has been an obstacle to the rationalization of construction work. Once this obstacle has been eliminated, concrete construction can be rationalized and a new construction system, including formwork, reinforcement, support and structural design can be developed.

2.6 APPLICATIONS OF SCC

The main targets for using SCC are construction parts with closely arranged reinforcement, construction parts with poor or without compaction possibilities, filigree construction parts, exposed concrete with high demand to surface quality, concrete with a textured surface and concrete works in an environment sensitive to noise. The main benefits from using SCC in building structures consist in shortening the construction period and thus increasing productivity, assuring compaction in the structure (particularly in confined zones where it is difficult in general) and so enhancing the construction quality and eliminating noise due to vibration which leads to substantial improvement of the working environment on site. After more than 20 years of development initiated in Japan in late 1980s, the use of SCC in building industry is quite common at present.

With growing shortage of construction workers due to aging population and increasing labour demand by the construction industry, SCC will be a useful material in achieving quality concrete construction. The effective use of man power, energy and materials with improved productivity contributes to the economic sustainability of concrete construction when SCC is used.

Key benefits of using SCC include an improved quality of the finished product, less remedial work, improved working environment, reduced noise, faster construction, reduction in the number of workers required, increased overall productivity and economy. But the production of
SCC plays more stringent requirements on the selection of materials in comparison with conventional concrete. Sometimes uncontrolled variation of even 1% moisture content in the fine aggregate will have a bigger impact on the rheology of SCC at very low water powder ratio. Proper stockpiling of aggregate, uniformity of moisture in the batching proceeds and good sampling practice are essential for SCC mixture. Development of SCC mixes requires a large number of a trial batches. In addition to the laboratory trial batches, field size trial batches should be used to simulate the typical production conditions. Once a promising mixture has been established, further trial batches are required to quantify the characteristics of the mixture.

SCC may be costlier than conventional concrete initially, perhaps due to higher dosage of chemical admixtures.

2.7 CONCRETE AND THE ENVIRONMENT

Construction industry is the largest user of natural resources in the world. The manufacture of cement consumes at least 20% of the total power production in the world. Power is produced mostly by burning coal that leads to environmental pollution. Energy-intensive manufacturing process of cement is a major source of carbon dioxide emissions. Due to large scale construction activities, cement, natural aggregate requirements have increased many times. Since approximately 75% of concrete volume is comprised of aggregate, the properties of the aggregate have an important influence on the properties of concrete.

Many countries in the world are witnessing a faster growth in infrastructure developments which involves the use of natural resources for the development of the infrastructure. This growth is jeopardized by the lack of natural resources that are available. The continuous and expanding extraction of natural aggregates causes serious environmental problems. Often
it leads to deterioration of the countryside. The sustainable development for construction involves the use of non-conventional and innovative materials, and recycling of waste materials in order to compensate the lack of natural resources and to find alternative ways for conserving the environment. Aggregates are considered one of the main constituents of concrete since they occupy more than 70% of the concrete matrix. The consumption of aggregates of all types has been increasing in recent years in most countries at a rate far exceeding that suggested by the growth rate of their construction industries. Due to this, in some countries there is scarcity of natural aggregates that are suitable for construction while in other countries, there is an increase in the consumption of aggregates due to the greater demand by the construction industry.

To reduce the environmental impact by construction industry, the long-term approach to lower the environmental impact of using any material is to reduce its rate of consumption. In the short-term, we must begin practicing industrial ecology for sustainable industrial development, involving the use of recycled waste products of one industry by substituting them for the virgin raw materials of another industry, thereby reducing the environmental impact of both. Consequently, it makes sense to explore other sources of high quality and inexpensive aggregates to produce SCC.

2.8 SUSTAINABLE CONSTRUCTION

The concept of sustainable construction is an approach to construction which promotes to attain goals associated with four process oriented “pillars” by Hashimoto et al. (1989). Sustainable construction must fulfil the following area.
• Economic sustainability: increasing profitability through efficient use of materials, energy and labour.

• Environmental sustainability: minimizing environmental impact by effective use of natural resources, reducing wastage and utilizing recycled materials.

• Social sustainability: meeting the people’s needs at all stages of construction, providing higher customer satisfaction and working closely with clients, suppliers, employees and local communities.

• Technical sustainability: Responding the availability of materials, technology, education, training and manpower to sustain construction and maintaining the built infrastructure.

Therefore sustainable construction has several objectives.

a) Promoting resource efficient building designs with prolonged service life with minimum maintenance.

b) Minimizing environmental impacts by reducing the use of natural materials and energy.

c) Reducing the manpower requirement.

In spite of the advantages in using SCC, the sustainability of concrete construction industry is questioned for a number of reasons. Firstly considerable amount of natural resources, materials, manpower and energy are consumed for the production of concrete making materials. Secondly portland cement production contributes around 5% of the total green house gas emissions out of all human activities resulting in global warming.
2.9 USE OF INDUSTRIAL BY-PRODUCTS IN CONCRETE

In the last few decades, there has been a rapid increase in the waste materials and by-products production due to the exponential growth rate of population, development of industry and technology and the growth of consumerism. Dumping or disposal of these waste materials cause environmental and health problems. Therefore, recycling the waste materials is the only solution available to minimise serious environmental hazardous. Solid waste management has gained significant importance with the ever-increasing quantities of waste materials that is contemporarily being generated. The basic strategies to decrease solid waste disposal problems have been focused as

i) Reduction of waste production and recovery of usable materials from waste as raw materials

ii) Utilization of wastes as raw materials whenever possible.

Availability of natural resources is reducing worldwide while at the same time, volume of generated wastes from the industry is increasing substantially. In order to reduce dependence on natural aggregates as the main source of aggregate in concrete, artificially manufactured aggregates and aggregates generated from industrial wastes provide an alternative for the construction industry. Therefore, utilization of aggregates from industrial wastes may become an alternative to the natural and artificial aggregates. Without proper alternate aggregates being utilized in the near future, the concrete industry globally will consume 20 to 22 billion tons annually of natural aggregates after the year 2020. Such large consumption of natural aggregates will cause destruction to the environment.
The major producers of industrial wastes are thermal power plants, iron and steel mills, non-ferrous industries and cement industries. The beneficial use of industrial by-products in concrete technology has been well known for many years. Hence significant research has been published with regard to the use of materials such as coal fly ash, pulverized fuel ash, blast furnace slag and silica fume as partial replacements for portland cement. Such materials are widely used in the construction of industrial and chemical plants because of their enhanced durability compared with portland cement. The other main advantage of using such materials is the cost effectiveness in construction.

The beneficial utilisation of some industrial by-products in improving the properties of fresh and hardened concrete was well recognised for many years. By-products such as pulverised fuel ash, silica fume and ground granulated blast furnace slag (GGBFS) are added in different proportions to concrete mixes as either a partial substitute to portland cement or as admixtures. Concrete prepared with such materials showed improvement in workability and durability compared to normal concrete and has been used in the construction of power and chemical plants and under-water structures.

2.10 CONCLUSIONS

SCC has the ability to fill formwork and encapsulate reinforcing bars only through the action of gravity and maintains homogeneity. Therefore SCC is an ideal solution for complicated structures. The world is witnessing a steady growth in the construction industry, resulting in a serious environmental impact. Since natural aggregates are considered one of the main constituents of concrete, quarrying of aggregates leads to disturbed surface area. Natural resources are depleting in many parts of the world. Due to industrial activities, wastes are generated in an uncontrolled manner. New
by-products and waste materials generated by various industries, dumping or disposal of these materials causes environmental and health problems. Therefore, reusing the waste materials for the manufacture of SCC may have a great potential in concrete industry.